Constellation Space Suit System Development Status

07ICES-131

Constellation Space Suit System Pressure Garment Development Status

Amy Ross, Lindsay Aitchison, Brian Daniel
National Aeronautics and Space Administration Johnson Space Center

ABSTRACT
The Constellation Program has initiated the first new flight suit development project since the Extravehicular Mobility Unit (EMU) was developed for the Space Shuttle Program in the 1970's. The Constellation suit system represents a significant challenge to designers in that the system is required to address all space suit functions needed through all missions and mission phases. This is in marked contrast to the EMU, which was designed specifically for micro-gravity space walks. The Constellation suit system must serve in all of the following scenarios: launch, entry and abort crew survival; micro-gravity extravehicular activity (EVA); and lunar (1/6th-gravity) surface EVA. This paper discusses technical efforts performed from May 2006 through February 2007 for the Constellation space suit system pressure garment.

INTRODUCTION
This paper covers the work performed by the space suit pressure garment and crew survivability teams from May 2006 through February 2007. Work during this period focused on feasibility studies, risk assessment, and requirements development. Crew survivability (CS) is inextricably intertwined with the pressure garment; therefore, they are discussed together.

WORK PERFORMED
Concept of Operations
The first task performed was to scope the EVA system. In keeping with the top-down requirements development methodology of the Constellation Program, this was accomplished by decomposing the program-level Concept of Operations into the system-level functional flow block diagrams (FFBDs). A Concept of Operations is a prose description of a program's mission and how each asset of the program is to be used to accomplish the mission. FFBDs capture the cradle-to-grave functions and, thus, all functional requirements associated with a system or a piece of hardware. Once the FFBDs had been established, a system-level Operations Concepts was written. The Operations Concept is the lower-level equivalent of the Concept of Operations. With initial stakeholder buy-in to the EVA System Operations Concept, functional requirements take form, thus allowing feasibility and risk assessment activities to begin. For example, joint range of motion requirements can be derived from functional gross mobility tasks that are specified in the Operations Concept.

Comment: This paragraph has inconsistent verb tenses. Are you trying to explain how things were done or how to complete the process in general?

The Pressure Garment team has continued to refine the EVA system-level Operations Concept and has worked to detail the engineering-level Operations Concept through a

series of Operations Concept walk-throughs in the Crew Exploration Vehicle (CEV) mock-up, which is housed in the Johnson Space Center (JSC) Space Vehicle Mock-up Facility, and at the JSC simulated planetary surface test area.

Reference Configuration Development

The Pressure Garment team supported two efforts that investigated Constellation pressure garment architectures. The first was an engineering-led brainstorming effort and the second was a Constellation EVA project-led effort to define architecture to be used by the program for costing exercises and initial studies. The on-going brainstorming effort is discussed below under Requirements Analysis Cycle 1. The development of the EVA project reference architecture is discussed below.

The Constellation EVA project-led reference architecture was developed over the course of a week by a team of EVA stakeholders that included Constellation EVA Project Office and engineering personnel and representatives from safety, the Astronaut Office, procurement, mission operations, and headquarters. The reference architecture developed by the team is illustrated in Table 1. The primary feature is that the architecture has a common lower torso for all mission phases and functions. The architecture includes two upper torsos. One upper torso, utilized in Configuration 1, combines crew survival and micro-gravity contingency EVA capability. The Configuration 2 upper torso is specialized for the planetary surface EVA. Environmental protection, harnesses, and ancillary hardware are removable/replaceable as mission usage requires.

Table 1: Reference Architecture

	Configuration 1	**Configuration 2**
Capability	Crew survivability (CS) and micro-gravity EVA	Lunar surface EVA
Upper Torso (including shoulders)	Specialized for CS with limited EVA capability. -Waist entry -Scye bearings perpendicular to the torso -Upper arm bearings	Specialized for surface EVA -Rear-entry -Scye location optimized for EVA -Upper arm bearings
Helmet	Common pressure bubble Specialized visor assembly Wedge element adapts the common bubble to the Configuration 1 upper torso	Specialized visor assembly
Lower Arms	Common	
Lower Torso	Common -2-bearing hip	

Boots	Common	
Environmental Protection Garment	Specialized for CS Specialized for micro-gravity EVA	Specialized for Lunar surface EVA, includes dust protection

Comment: Either add detail or change title of table to indicate that this table is only looking at differences b/t configs 1 and 2.

The reference architecture is being used as a tool by the pressure garment engineering team to assess risk and feasibility. Risks associated with the reference architecture have been identified and are being investigated. Additionally, as a part of the risk mitigation work, alternate architectures from the reference have been identified and are also being investigated.

Comment: This is capitalized in previous sections.

Requirements Analysis Cycle 1

The Space Suit Element team is using requirements analysis cycles (RAC) to address areas of risk, feasibility and requirements uncertainty. Sub-system leads and the system engineering and integration team work together to define RAC content. The results of RAC 1 are reviewed here. The content of RAC 2 is listed. The RAC 2 results are due in May of 2007, prior to the Suit System Requirements Review (Suit SRR).

Comment: Based on…?

<u>Pressure Garment (PG) Brainstorming</u>

A brainstorming activity was undertaken to explore creative approaches to the pressure garment architecture. Brainstorming was performed on the following components: helmet, shoulder, torso, arms, gloves, hip/waist, leg, and boot. The activity employed the following process:

1. Generate a list of functional requirements for the crew survival and lunar surface EVA tasks for each of the components
2. Identify which requirements are common; identify which components have enough requirements in common to consider them common components across mission capabilities
3. Brainstorm concepts for each component
4. Perform a positive evaluation of the component concepts
5. Perform a pessimistic evaluation of the component concepts
6. Eliminate component concepts for which the negatives outweigh the positives
8. Create PG concepts by combining component concepts
9. Perform positive and pessimistic evaluation of the PG concepts
10. Evaluate and downselect PG concepts using the positives and negatives identified in Step 9.
11. Generate a list of evaluation criteria and weightings by consensus
12. Evaluate PG concepts
13. Downselect to 1 or 2 concepts to carry forward
14. Generate a technology development plan

Steps 1-10 have been completed to date. A number of component concepts were generated. The team, due to time limitations, decided to concentrate on upper torso and hip/waist components in creating and evaluating the PG concepts in steps 8 and 9 because

they form the heart of PG design. Components such as lower arms (elbows), lower legs (knees), boots, helmets and gloves were considered to be easily interchangeable.

The team is performing the final PG concept evaluations prior to the suit system requirements review. Final concept(s) will be used to determine technology development needs and to evaluate against the reference architecture.

Comment: I don't know what is meant by this.

<u>Thermal Analysis</u>

The thermal performance of the suit affects not only pressure garment design, but also vehicle life support and portable life support designs. Therefore, one of the first efforts was to perform a parametric study of the thermal performance of the PG in the following mission scenarios:

- Micro-gravity EVA in low Earth orbit and low Lunar Orbit
- Long-duration unpressurized cabin
- Nominal launch and landing
- Off-nominal launch
- Off-nominal landing, cold water
- Off-nominal landing, cold and hot land

The analysis highlighted a suit architectural decision that must be made. The design team must either choose an insulative suit or a conductive suit. An insulative suit is best for cold water survival. However, even for moderate levels of insulation, over-heating problems arise quickly in warm Earth environments. Therefore a decision must be made regarding the pressure garment thermal characteristics and then accommodations must be made for the scenarios not well addressed by the pressure garment design.

Follow-on thermal analysis is examining Lunar EVA thermal scenarios.

<u>Suit Sizing</u>

The Constellation Program is required to accommodate humans with dimensions ranging from the 1st to the 99th percentile in sixteen dimensions as determined from 2015 projections of the 1988 U.S Army Anthropometric Survey (ANSUR) database. However, the suit sizing task identified a need to go beyond the generation of sizing requirements. The task generated a comprehensive methodology for suit sizing design and verification. The suit sizing task identified the following forward work to create a comprehensive suit sizing design approach:

1. Perform a correlation analysis that limits the pressure garment sizing requirements to realistic combinations of the sixteen anthropometric dimensions
2. Develop a user-interface to the complete set of 2015 projections of the ANSUR
    -The user interface will include various statistical tools
3. Develop CAD-based boundary human manikins to be used for suit design and sizing verification
    -Boundary manikins will be placed in multiple functional postures
4. Generate fit criteria

-The fit criteria will be validated by correlation of subject-to-suit fit evaluations with a current suit configuration(s).

This approach is expected to improve the design for sizing across the anthropometric range and to improve the fidelity of pressure garment sizing verification.

Light-weight, low-profile pressure garment hardware task

Mass is always one of the critical design considerations for all space hardware. The majority of the weight of the pressure garment is carried in the bearings of the joint mobility systems and in the disconnects between PG components. Further, the profiles of bearings and disconnects have impacts on the mobility system design, comfort, and sizing capability. Therefore, a task was performed to minimize bearing and disconnect mass and profile. The task obtained a weight reduction of almost 70%, as compared to the equivalent bearings of the Extravehicular Mobility Unit (EMU), the current Space Shuttle/International Space Station flight program suit. Prototypes of the bearings are being fabricated for evaluation.

Waste Management

The Constellation program has identified a scenario in which a loss of cabin pressure during a lunar mission would require the crew to spend over 5 days (120 hours) in their space suit for their return to Earth. Although waste management is provided for in current crew survival and EVA suits, the certified 8-hour capacity of these systems is inadequate. The waste management task performed a survey of state-of-the-art waste management hardware and techniques. Information was gathered from the military and medical fields. The results of the market survey indicated that current off-the-shelf hardware does not meet all of the anticipated requirements for the Constellation program.

Survey of State-of-the-Art Survival Gear

A market survey to investigate the state-of the-art of survival gear was performed. Specific areas of interest included life rafts, life preservers, orthostatic intolerance protection garments and cold water protection. The studies suggest some creative solutions for each of the areas. From the survey results, it is expected that no technology development will be required for life rafts and life preservers. Priority for life raft selection will be placed on a thorough understanding of life raft use scenarios so that the correct life raft can be specified. Life preserver work will focus on integration of the preserver onto the pressure garment. For orthostatic intolerance protection, both passive and active garments are being considered. The historical and market surveys are being supplemented by performance characterization testing of a passive garment design. Finally, a market survey of current active and passive thermal protection technologies to protect crewmembers during long-duration cold water exposure was performed. The relatively low technology readiness and reliability of active systems discouraged sole dependency on only active or passive system. Further, the efficacy of a fully passive system for long-duration water survival remains an open question. As noted above, the pressure garment and crew survivability teams have yet to determine if cold water survivability will be integrated into the base pressure garment design or if cold water protection will be provided via alternate means.

Additional Activity
Two principle tests were performed in addition to the RAC 1 cycle work. These are discussed below.

Suit Donning Time Test
In case of a vehicle cabin leak, the vehicle life support is sized to maintain a life-sustaining cabin pressure while the crewmembers don their pressure suits. The working assumption was that the vehicle would 'feed the leak' for one hour. The suit donning test was an initial feasibility assessment to understand if it was reasonable to expect that a crew of six could don suits within the proposed 'feed the leak' time frame. The test was performed with the Advanced Crew Escape Suit (ACES). The study also provided an opportunity for suit engineers to study the donning process in order to understand what suit design aspect did or did not allow crewmembers to don their suits quickly. The suit donning time was measured as the time it took for six crewmembers to have performed the following activities:

- -don the ACES Liquid Cooling Garment
- -don theACES garment
- -don gloves
- -don the helmet
- -positioned in seat, cables and umbilicals connected

The test had several limitations. Primary among them, the crew commented that 1-G suit donning was not analogous to micro-gravity suit donning. However, the initial feasibility assessment was that suit donning could be accomplished within a one hour 'feed the leak' window.

Suit engineers observing the scenario noted several items that affected suit donning time. The items fell into three categories: suit design, vehicle design, and ancillary equipment design. For example, dealing with excess suit bladder and difficult to open suit stowage bags slowed suit donning while hand holds and other methods of body stabilization aided donning.

C-9 Facility Evaluation
Reduced gravity testing is critical to understanding true pressure garment mobility, task performance capability, and suit-to-vehicle interfaces. However, NASA Johnson Space Center retired the KC-135 aircraft and now utilizes a C-9. The diameter and length of the C-9 are smaller than that available in the KC-135. Thus, a test was performed to evaluate the C-9 reduced gravity aircraft to understand which suit tests could and could not be performed on the aircraft. The team determined that the width of the aircraft, not the height as anticipated, constituted the greatest restriction. The reduced width restricted the mobility tasks of the suited subject, the ability of the space suit technicians to translate with the subjects, the inclusion of motion capture hardware, and the ability to perform side-by-side translations. Therefore, tests will be evaluated on a case-by-case basis to determine if test objectives can be achieved in the C-9 aircraft. The test team recommended investigation of alternate reduced gravity aircraft test capability.

FORWARD WORK

Forward work is focused on supporting the Suit System Requirements Review. The SRR is the program milestone that directly precedes the preliminary design review. RAC cycle 2 topics are listed below:

Pressure Garment:

- Nominal and off-nominal operating pressure impacts on pressure garment design
- Mobility Requirements - micro-G, 1-G, and lunar Surface operations
- Pressure garment sizing tool development
- Pressure garment reference architecture brainstorming effort completion
- Liquid cooling garment architecture
- Weight and volume allocation
- Interfaces for removable/replaceable cover layers

Crew Survivability:

- Common helmet study and risk mitigation
- Crew survival architecture
- Crew strength de-rating due to deconditioning

The pressure garment reference architecture task is being addressed through a series of risk mitigation and feasibility assessment testing. One of the first tests in the series will be performed in May aboard the reduced gravity aircraft. Micro-gravity don and doff of various suit configurations is a test objective. Integrated testing to look at suit interfaces with the CEV side hatch size and the docking tunnel will also be conducted.

SUMMARY

The pressure garment and crew survivability teams have been working to address fundamental design issues. The work has enabled the team to begin to ask better questions and to focus effort in areas of greatest risk. Determining the best obtainable suit architecture continues to be a challenge.

The reports for the majority of the work discussed above will made available on the Constellation Space Suit System procurement website. http://procurement.jsc.nasa.gov/csss/default.asp

Comment: This seems a bit weak, but I'll try to figure out a few suggestions.

Comment: II think that the paper would benefit from some conceptual drawings and photographs to help the reader understand the text.